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# Impact of Beacon Coverage on Clustering Strategies for Fingerprinting Localization System

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**Abstract**—Among the various indoor localization systems, received signal strength (RSS) based fingerprinting localization provides most cost-effective solution as it uses the existing wireless network infrastructure. The positioning accuracy of such localization systems can be improved by incorporating huge number of training data, which in turn, increases the searching overhead of such localization systems. Several clustering strategies for fingerprinting localization have been proposed in literature in order to reduce the searching overhead. On the other hand, placement strategy of beacon nodes within the field of localization has significant influence on the performances of clustering strategies for fingerprinting localization. Two important factors associated with some beacon placement strategy are the degree of beacon coverage and the distribution of beacon nodes. In this paper, we present an optimal beacon placement strategy that meets a k-coverage visibility requirement for beacons at every point within the field of localization. Next, we demonstrate the impact of beacon coverage on the performance of several clustering strategies suitable for a large-scale fingerprinting localization system.

**Keywords**—received signal strength (RSS), fingerprinting localization, beacon coverage, clustering strategy

## I. INTRODUCTION

A received signal strength (RSS) based fingerprinting localization system works in two phases to provide location estimation. In the first phase known as training phase, RSS measurements from several access points (APs) or beacons are collected at a set of predefined training locations and those RSS patterns along with the positional coordinates of those training locations are stored inside a database called fingerprint database. The second phase called positioning phase compares the currently observed RSS pattern provided by an object with all RSS patterns stored within the fingerprint database and takes the location associated with best matched RSS pattern as the estimated location. Such localization system can provide accurate location estimation if its fingerprint database includes larger number of training locations, which in turn, increases the positioning time, i.e., the searching time in the positioning phase. The clustering strategy that partitions a large set of training data into several smaller subsets called clusters has been adopted by the fingerprinting localization systems proposed in [1, 2, 3, 4, 5, 6, 7] in order to reduce the positioning time. Among the various clustering techniques, the technique proposed in [1] forms the clusters by grouping the training locations which obtain the strongest signal strength from same set of APs or

beacons into one cluster. This technique is very easy to implement but it is hard to predict how many clusters will be created. In [2], the clusters are formed based on the geographical coordinate of the training locations, i.e., the neighbouring training locations are grouped into one cluster.

The k-means algorithm [3] has been employed for clustering in [4, 5]. The random selection of the initial member of each cluster created by k-means algorithm based clustering technique increases the possibility of false cluster selection. In order to reduce the chances of false cluster selection, two clustering strategies that allow overlap among the clusters generated by the k-means algorithm, multi-nearest-neighbour (MNN) overlapping strategy and Voronoi-based overlapping strategy, have been proposed in [6]. However, both overlapping strategies increase the positioning time and incur higher computational complexity compared to k-means algorithm. In [7], we have proposed a novel clustering strategy, hierarchical clustering strategy (HCS), which forms the clusters in a hierarchical way based on which beacon or AP provides strongest signal strength at some particular training location. Our proposed technique [7] is very easy to implement and the number of clusters created by it can be easily determined unlike the technique proposed in [1]. Therefore, among the various clustering strategies proposed for RSS-based fingerprinting localization systems in the literature, k-means algorithm-based strategy [4, 5], two overlapping strategies [6] (MNN and Voronoi) and our proposed strategy HCS [7] are highly suitable for largescale fingerprinting localization systems. Beacon placement strategy has a significant influence on the localization accuracy of the localization system [8]. Two important properties of a beacon placement strategy are the degree of beacon coverage and the distribution of beacon nodes. The degree of beacon coverage indicates the density of beacon nodes in the area of localization and higher density of beacon nodes can improve the localization accuracy [8]. The problem of k-coverage visibility requirement in wireless sensor network is addressed in [9, 10]. The classical triangle lattice pattern [11] can be applied to achieve 1-coverage visibility requirement for beacon nodes. The classical triangle lattice pattern as shown in Fig. 1 covers an area by equilateral triangles (grey shaded) and ensures 1-coverage visibility requirement if a beacon is placed at the centroid of each grey shaded triangle. The length of each side of these equilateral triangles is set to  $\sqrt{3}R$ , where  $R$  is the radius of the communication range of each beacon. The authors in [8]

have devised a cost-effective method of beacon placement strategy that can meet  $k$ -coverage visibility requirement for

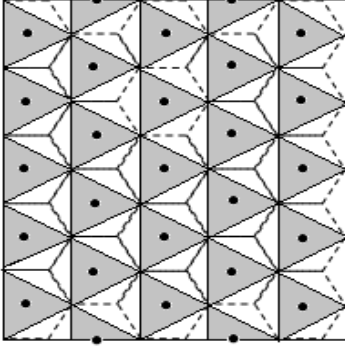


Fig. 1. Triangle Lattice Pattern

an arbitrarily shaped area by extending the concept of triangle lattice pattern and also analysed theoretically the lower bound and upper bound of the number of beacon nodes to meet  $k$ -coverage visibility requirement. However, the lower bound on the number of beacon nodes provided in [8] does not meet the  $k$ -coverage visibility requirement. In the fingerprinting localization systems [12, 13], each training location is equally important and thus uniform placement of beacon nodes is highly desirable for fingerprinting localization system. To the best of our knowledge, no existing work on fingerprinting localization system has considered the effect of beacon coverage on the positioning accuracy of the localization system. Thus, in this paper, we present an optimal beacon placement strategy that ensures sufficient beacon coverage at every training location within the field of localization and show the effect of different degree of beacon coverage on the performances of above-mentioned clustering techniques proposed for fingerprinting localization system.

## II. PROPOSED BEACON PLACEMENT STRATEGY

Our proposed beacon placement strategy utilizes triangle lattice pattern as depicted in Fig. 1 to achieve 1-coverage visibility requirement and then extends the concept of triangle lattice pattern to achieve  $k$ -coverage visibility requirement for beacon nodes in the area of interest. The proposed beacon placement strategy is illustrated by Fig. 2 and it can be applied to an arbitrary shaped area as described below. We consider the arbitrary shaped area ABEFGH as the field of localization and it is surrounded by rectangular area ABCD as shown in Fig. 2(a). Fig. 2(b) illustrates the placement of beacon nodes by our proposed strategy at the small black circles within the rectangular area ABCD to achieve 1-coverage beacon placement. The proposed beacon placement algorithm is described below.

1. If the field of localization is not rectangular, it will be surrounded by a rectangle as shown in Fig. 2(a). Let the positional co-ordinates for points A, B, C and D are  $(x_{mn}, y_{mn})$ ;  $(x_{mx}, y_{mx})$ ;  $(x_{mx}, y_{mx})$  and  $(x_{mn}, y_{mn})$  respectively. Thus, the width ( $W$ ) and length ( $L$ ) for the rectangular area ABCD can be determined as  $W = x_{mx} - x_{mn}$ ;  $L = y_{mx} - y_{mn}$ .

2. The rectangular area is divided into some vertical slices whose width ( $cw$ ) is  $3R/(k+1)$ , where  $R$  is the radius of communication range of the beacon nodes and  $k$  is the degree of beacon coverage. The number of vertical columns along which beacon nodes should be placed is determined as  $NoVC = 1 + W/cw$ . Along any vertical column, the distance between two consecutive APs ( $apd$ ) is set to  $\sqrt{3}R/k$ , where  $k$  is the degree of beacon coverage.
3.  $i \leftarrow 1$ . Execute all the following steps iteratively until  $i > NoVC$ .
  - a.  $x_{bp} \leftarrow x_{mn} + (i-1)cw$ .
  - b. if  $x_{bp} > x_{mx}$ ,  $x_{bp} \leftarrow x_{mx}$ .
  - c. If  $i$  is odd number,  $y_{bp} \leftarrow y_{mn}$ . Else,  $y_{bp} \leftarrow y_{mn} + apd/2$ .
  - d. Place a beacon node at position  $(x_{bp}, y_{bp})$ . Execute all the following steps iteratively until  $y_{bp} \geq y_{mx}$ .
    - i.  $y_{bp} \leftarrow y_{bp} + apd$
    - ii. if  $y_{bp} > y_{mx}$ ,  $y_{bp} \leftarrow y_{mx}$
    - iii. Place beacon node at position  $(x_{bp}, y_{bp})$ .

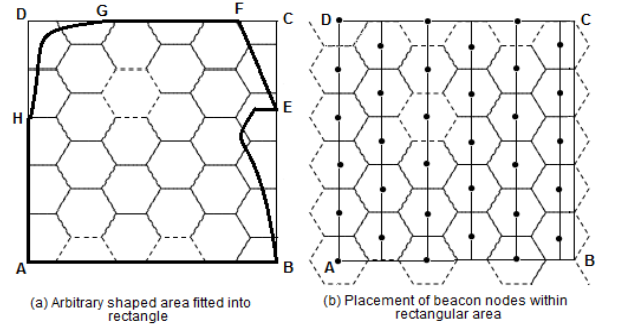


Fig. 2. Illustration of Proposed beacon placement Strategy

## III. PERFORMANCE EVALUATION

This section, at first, provides a short description of the clustering strategies suitable for large-scale fingerprinting localization systems and then the impact of beacon coverage on their performances have been observed by applying our proposed beacon placement strategy presented in previous section, in a test area which is of size  $250m \times 250m$ . The performances of the clustering strategies are compared in terms of positioning time and positioning error with respect to different values of the beacon coverage that varies within the range of 1 to 5. Both the propagation models, i.e., free-space propagation model [4] and radio irregularity model (RIM) [14] have been applied in the simulation test area to determine RSS measurements at the training locations. Finally, a graphical result on variation of beacon deployment density (number of beacons per square meter) with different values of beacon coverage is presented.

### A. Clustering strategies for large-scale localization system

This section describes in brief k-means algorithm based clustering strategy [3], two overlapping clustering strategies [6] and hierarchical clustering strategy (HCS) [7].

1) *K-Means algorithm based clustering strategy*: The  $k$ -means algorithm has been adopted in [4, 5] to create  $k$  clusters using a recursive method. The procedure to divide all training RSS patterns into  $k$  subsets is described below.

i. The number of iterations ( $x$ ) to be executed to form  $k$  clusters is determined as  $x = \lceil n \rceil / k$ , where  $n$  is the total number of training locations within the field of localization. In first iteration,  $k$  RSS patterns are selected randomly from the set of all RSS measurements taken at  $n$  training locations. These  $k$  RSS vectors become the initial member of  $k$  clusters.

ii. The representative RSS pattern for each cluster is determined by averaging all RSS patterns belonging to it.

iii. In the subsequent iterations following the first one, each of the remaining RSS patterns within the set  $V$  is compared with the representative RSS pattern of all  $k$  clusters and it is included into that cluster whose representative RSS pattern has the shortest Euclidean distance [15] from that selected RSS pattern.

In the positioning phase, this strategy, at first, compares the measured RSS pattern provided by some object with the representative RSS patterns of all clusters and selects the cluster whose representative RSS pattern has shortest Euclidean distance from the measured RSS pattern. Then it applies Nearest Neighbour in Signal Space (NNSS) [16] algorithm to estimate the position of the object.

2) *Overlapping clustering strategies*: Multi-nearest neighbour (MNN) overlapping strategy and Voronoi-based (VRN) overlapping strategy allow overlap among the clusters generated by the  $k$ -means algorithm have been proposed in [6] in order to enhance the positioning accuracy of the localization system. Both overlapping strategies determine the location of the object in the positioning phase in the same way as the  $k$ -means algorithm based strategy. Simulation results in [10] demonstrate that the VRN overlapping strategy is more effective in the sparse environment compared to the MNN overlapping strategy. The MNN overlapping strategy, at first, applies  $k$ -means algorithm to create  $k$  clusters and then allows each training data (RSS) to join some fixed number other clusters based on the value of its overlapping degree.

MNN assigns a constant overlapping degree ( $\mu$ ;  $\mu > 0$ ) to each training data. Thus, each training data in this strategy joins the first  $\mu$  clusters within the list of all clusters sorted in ascending order by the Euclidean distance [15] between cluster's representative RSS vector and training RSS vector.

On the other hand, according to VRN overlapping strategy, if the measured RSS vector at some training location is far away from the centre of a cluster then it is more likely to join higher number of clusters compared to another location whose measured RSS vector is nearer to the centre of the cluster. VRN overlapping strategy introduces a new variable called expansion range ( $\epsilon$ ) to define the overlapping region around the Voronoi edge between any

pair of Voronoi cells. Some RSS vector  $R_i$  is considered to be within the overlapping region between the Voronoi cells  $V_i$  and  $V_j$ , if the vertical distance from vector  $R_i$  to the Voronoi edge between those two cells is less than the predefined value of  $\epsilon$ . According to this strategy, any training data already belonging to  $V_i$ , would be allowed to join  $V_j$  also if the RSS vector for that training data lies within the overlapping region between the cells  $V_i$  and  $V_j$ .

3) *Hierarchical clustering strategy (HCS)*: The hierarchical clustering strategy (HCS) [11] groups the training locations into a cluster if those training locations observe strongest signal strength from one particular AP. HCS divides the whole radio map into several non-overlapping clusters in some fixed number of iterative steps determined by its level of hierarchy. At the first step, the number of generated clusters is equal to the number of APs deployed in the field of localization. In the second step, each of these clusters, represented by  $C_i$ , ( $1 \leq i \leq m$ , where  $m$  is the number of APs) can be further divided into several sub-clusters ( $C_{i1}, C_{i2}, \dots, C_{ip}$ ) if the training locations belonging to that cluster receive the second highest signal strength from different neighbouring APs ( $1, 2, \dots, p$ ). In positioning phase, HCS at first selects an appropriate cluster based on the descending order of Aps having strongest signal strength in the measured RSS pattern provided by an object. The measured RSS pattern is then compared with all the RSS patterns belonging to the selected cluster only to determine the position of the object by applying NNSS [16]. Both clustering strategies, 1-way HCS and 2-way HCS, are described in detail in [7].

## B. Performance metrics

The following performance metrics have been considered.

*Positioning Time*: It is the duration of time interval between the instance the location of some object is determined and the instance request for localization is made in the positioning phase.

*Positioning Error*: It is defined as the distance between the estimated position provided by some fingerprinting localization technique and the true position of the object.

## C. Performance evaluation-free-space propagation model

The free-space propagation model is based on perfect spherical radio propagation and identical transmission range for all radios. In free-space propagation model, the RSS measurement at each training location can be inferred by equation (1).

$$PL(D) = PL(D_0) + 10\gamma \log(D/D_0) + N(0, \sigma), \quad (1)$$

where  $D_0 = 1$  is the reference distance and  $D$  is the distance between the transmitting AP and the receiving mobile node, term denotes the path loss exponent whose value varies within the range of 2 to 6 and  $N(0, \sigma)$  is a normal distributed random variable having zero mean and a standard deviation  $\sigma$ . The received signal strength at distance  $D$  is calculated by  $P_t - PL(D)$ , where  $P_t$  represents the

transmitting power which is set to 15 dBm. The default value for parameters  $PL(D_0)$ ,  $\gamma$  and  $\sigma$  are 37.3, 4 and 4 respectively.

Figs. 3 and 4 compare the performances of various clustering strategies in terms of positioning time and positioning error respectively under different values of beacon coverage. Fig. 3 shows that positioning time for our proposed strategies 2-way HCS and 1-way HCS increases sharply whereas that for other existing strategies increases very slowly. This is so because our proposed strategies compare signal strength values provided by different beacon nodes visible at that location to select the cluster in the positioning phase and this cluster selection time increases as the value of beacon coverage increases. On the other hand, cluster selection time for other existing strategies does not depend on value of beacon coverage. Fig. 3 also demonstrates that the searching overhead of our proposed strategies are better than that of the existing strategies. Fig. 4 shows that positioning error for the various strategies considered in this paper reduces with the increasing value of beacon coverage which is expected usually. Fig. 4 also depicts that our proposed clustering strategies 2-way HCS and 1-way HCS provides better result in terms of positioning error compared to other existing strategies considered here.

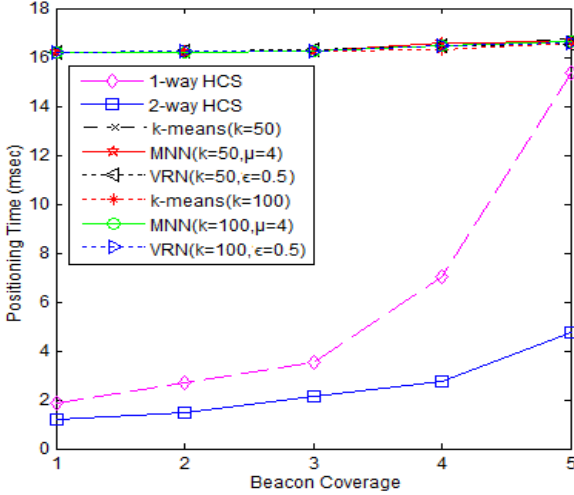


Fig. 3. Positioning time vs Beacon coverage.

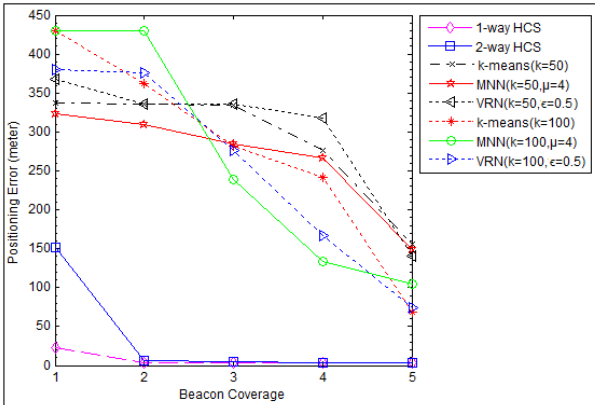


Fig. 4. Positioning error vs Beacon coverage

#### D. Performance evaluation under the presence of noise

Radio irregularity is a common phenomenon in wireless environment. It is mainly caused by the non-isotropic properties of the propagation media and the heterogeneous properties of devices [14]. Thus the performances of various clustering strategies are compared in terms of positioning time and positioning error in Figs. 5 and 6 respectively by considering the presence of radio irregularity in wireless environment. Some horizontal and vertical walls are considered along the line segments  $([25i, -125], [25i, 125])$  and  $([-125, 25i], [125, 25i])$ ,  $-5 \leq i \leq 5$  in the test area to create obstacles within the field of localization. The RSS measurement in presence of RIM model can be inferred at each training location by using the following equation.

$$P_r(l, AP_j) = P_t^{VSP}(AP_j) - PL^{DOI}(l, AP_j) - PL^{WAF}(l, AP_j) + N(0, \sigma), \quad (2)$$

where  $P_r(l, AP_j)$  indicates the amount of received power at some location  $l$  from the  $j$ th AP ( $AP_j$ ),  $P_t^{VSP}(AP_j)$  denotes the power transmitted by the  $j$ th AP,  $PL^{DOI}(l, AP_j)$  denotes the path loss at location  $l$  from the  $j$ th AP due to the non-isotropic and continuous variation of radio signal within wireless environment,  $PL^{WAF}(l, AP_j)$  denotes the path loss caused by the obstacles at location  $l$  from the  $j$ th AP and  $N(0, \sigma)$  denotes the amount of noise. In RIM, VSP stands for variance of sending power, DOI means the degree of irregularity which determines the amount of path loss in different directions and WAF denotes wall attenuation factor. Because of the lack of space, the mathematical modelling of  $P_t^{VSP}(AP_j)$ ,  $PL^{DOI}(l, AP_j)$  and  $PL^{WAF}(l, AP_j)$  cannot be provided in this paper. These are available in [14].

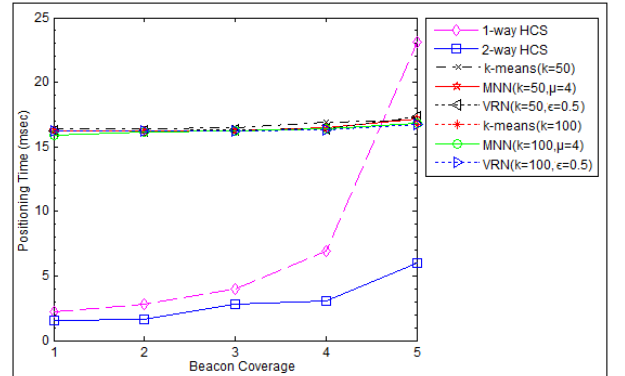


Fig. 5. Positioning time vs Beacon coverage.

Fig. 5 shows that the searching overhead of all strategies considered in this paper increases with the increasing value of beacon coverage under radio irregularity model just like free-space propagation model. Fig. 5 also shows that presence of radio irregularity in wireless environment increases the searching overhead for our proposed strategy 1-way HCS whereas that for other strategies remains unaffected. Fig. 6 shows that the performances of all clustering strategies considered in this paper degrade slightly in terms of positioning accuracy under the radio irregularity model compared to free-space propagation model. Fig. 6 also depicts that our proposed strategies outperforms the other

existing strategies in terms of positioning accuracy in presence of radio irregularity in wireless environment.

Fig. 7 shows how the values of beacon density in unit of number of beacons per square meter vary with the different values of beacon coverage. Fig. 7 depicts that beacon deployment density increases with the increasing values of beacon coverage.

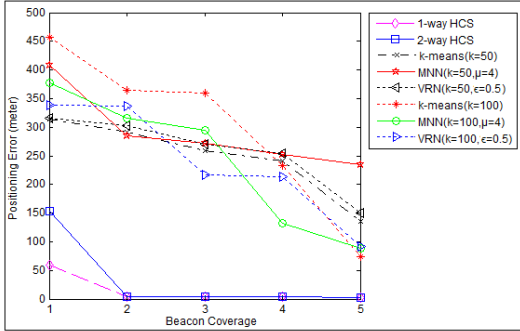


Fig. 6. Positioning error vs Beacon coverage.

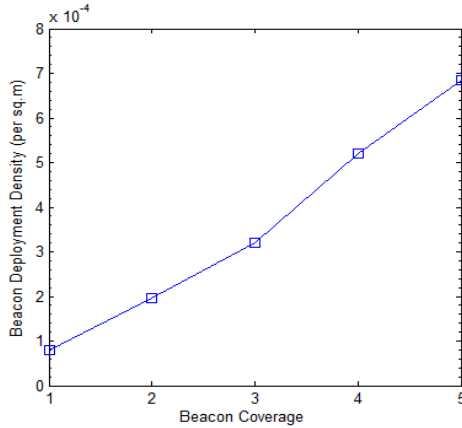


Fig. 7. Beacon deployment density vs beacon coverage.

#### IV. CONCLUSIONS

This paper presents an optimal beacon placement strategy that ensures  $k$ -coverage visibility requirement at every point within the area of localization for fingerprinting localization system,  $k$  is a positive integer. In this paper, we have evaluated and compared the performances of several clustering strategies suitable for large-scale fingerprinting localization systems in terms of searching overhead and positing accuracy under the different values of the beacon coverage. The simulation results provided in this paper show that positioning accuracy for all the clustering strategies considered in this paper improves with the increasing value of the degree of beacon coverage. However, the performances of those clustering strategies in terms of searching overhead degrade with the increasing value of the degree of beacon coverage. Experimental results provided in this paper also depict the fact that positioning accuracy of clustering based fingerprinting localization system degrades under the presence of noise in simulation test area.

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